

An Automated Tool for Mission Planning in GPS-Denied Areas

Michael Grace, Peter Stieber, *Toyon Research Corporation, Santa Barbara, CA*

Steven Minarik, Bereket Tanju, Fernando Escobar, *U.S. Navy Space and Naval Warfare Systems Command (PMW/PMA-156), San Diego, CA*

BIOGRAPHY

Mike Grace is Director of RF Systems at Toyon Research Corporation in Santa Barbara. He has a BA Human Biology from Stanford University, a BS Mathematics from U.C. Santa Barbara, and an MSEE from the University of Southern California.

Pete Stieber is a senior staff analyst at Toyon Research. He holds both a BS and an MSEE from the University of Illinois and is Toyon's lead software developer for several programs related to GPS software and antenna programs.

Steve Minarik serves as the Assistant Program Manager for Advanced Technology within the Navy's Navigation Systems Program Office. He has a BSEE from the University of Maryland and an MSEE from Villanova University. In the office, he is responsible for SBIRs, advanced developments, and special programs.

Bereket Tanju serves as the Assistant Program Manager for GPS Modernization within the Navy's Navigation Systems Program Office. He holds a BSEE from the University of Maryland and an MSIE from PennState. In the office, he is responsible for the Navy's Navigation Warfare and GPS Modernization Programs.

Fernando J. Escobar received his B.S. Mathematics and M.S. Physics from Utah State University, Logan, Utah. From 1989-1998, he worked in the Research Department of the Naval Air Warfare Center Weapons Division developing algorithms for EM scattering problems. He is currently with the GPS & Navigation System Research Group at SPAWAR Systems Center, San Diego, CA, where he is enrolled in the Naval Postgraduate School Software Engineering program. His areas of expertise include modeling and simulation of complex adaptive systems, high performance computing, and object oriented analysis, design, & programming.

ABSTRACT

GPS is critical to many military and civilian systems. It is therefore incumbent upon operational planners to ensure GPS integrity to friendly military forces and civilians, provide protection from GPS-guided weapons, and conduct testing of advanced, anti-jam equipment for use in GPS-denied areas. In order to support these complementary planning functions, the Navy is developing a software toolbox to evaluate GPS performance in specific scenarios, to automatically optimize vehicle routes to avoid GPS jamming, and to optimize placement and configuration of self-protection jammers or jammers used in testing anti-jam GPS equipment. The toolbox includes multiple optimization algorithms, various propagation algorithms suited to different conditions, a flexible software architecture for controlling optimization, and an intuitive graphical user interface. A prototype version of the toolbox has been delivered to the Navy. This paper describes the design and features of the software and presents an example of optimal jammer placement for an equipment test scenario.

INTRODUCTION

The Global Positioning System (GPS) has revolutionized geolocation and navigation and is now a mission-critical system supporting U.S. military forces through all levels of conflict. However, the commercial availability of low-cost receivers as well as nations exporting GPS jammers creates difficult problems for the operational planners who must plan operations in GPS-denied areas as well as provide protection of friendly forces from GPS-guided weapons.

For the example, self-protection using jammers may affect friendly- and enemy GPS receivers alike. It is therefore very important to precisely control the level of jamming energy and where the energy is directed so that friendly receivers are minimally affected. Considering all possible jammer configurations and the complexities of predicting the effects

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for a given configuration, the problem of finding the best solution becomes an onerous one.

The GPS Intelligent Jammer Evaluation Tool (GIJET™) is a PC-based, software application developed by Toyon Research Corporation that allows users to evaluate GPS performance, to find the best routes through GPS-denied areas, and to optimally position and configure GPS jammers in the battlefield or on the test range. Under an SBIR Phase I contract with the Navy, Toyon Research Corporation developed a prototype version of GIJET™ (see Figure 1). This paper describes the features of GIJET™ via an example of optimal jammer placement at a test range.

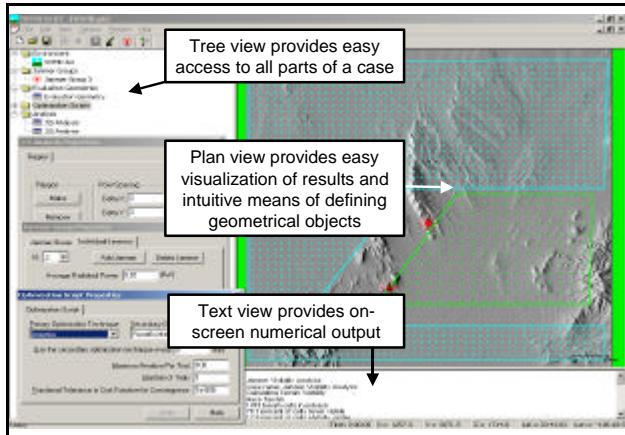


Figure 1 Example screen-shot shows three views of the GIJET™ jammer placement tool.

FEATURES OF GIJET™

The problem of covering a specific region in space with jamming energy while avoiding spillover of jammer energy into other regions can be extremely complex in general. We begin this discussion by describing a simple example that highlights the key elements of Toyon's approach to the jammer placement problem and the capabilities of the GIJET™ prototype. We will then describe planned enhancements to the tool, such as route planning support.

Consider a simple two-dimensional example where we want to cover a region with jamming energy while excluding the surrounding region from detrimental effects (Figure 2). The hypothetical scenario is a test of a GPS-guided weapon at the White Sands Missile Range (WSMR). We assume two available jammers in this example that are constrained to be located in a zone as shown in Figure 3. The jammers are further assumed to radiate ten Watts of RF noise matched to the L1-band and have omnidirectional antenna radiation patterns with the antenna assumed to be fixed atop a two-meter pole. With these simplifying assumptions, the optimizer is only allowed to move the jammers to take

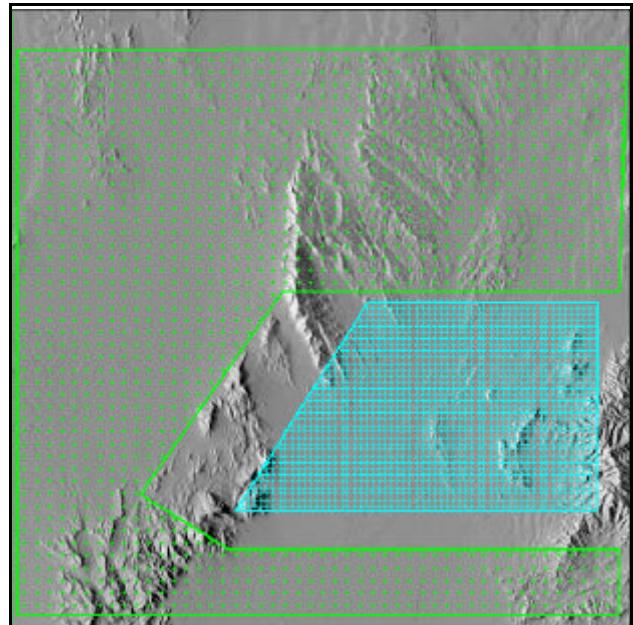


Figure 2 Simple two-dimensional GPS jamming problem. The blue-hatched region indicates where jamming is desired while green indicates where jamming is undesirable. The terrain used in this example is part of the White Sands Missile Range.

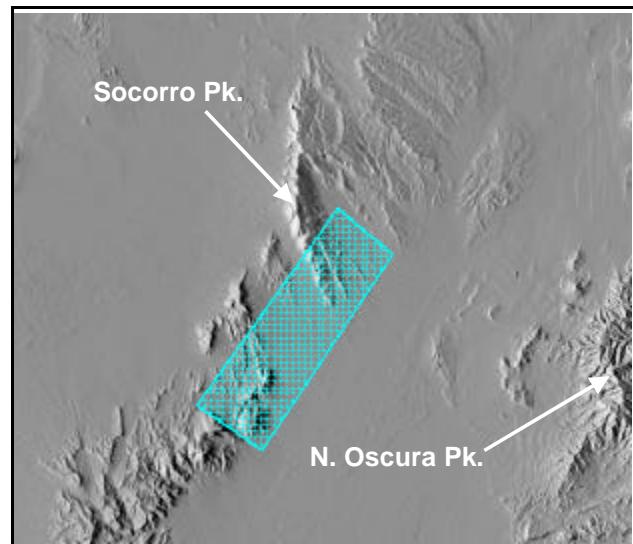


Figure 3 Example jammer deployment region indicated by the blue hatched area. The WSMR terrain features are more evident in this figure.

advantage of terrain masking and the fall-off in jammer signal strength with range to control the distribution of jamming energy.

The desired jam/no-jam regions are termed evaluation regions in GIJET™. GPS performance is defined in these regions by evaluation at a grid of hypothetical GPS receiver

locations. At each point in the grid, GIJET™ calculates the receivers' signal-to-noise-plus-interference power ratio (SINR) for each SV signal and for a given set of jammers. These ratios are then compared with thresholds that determine the loop tracking state within the receiver and the accuracy of the resulting GPS solution.

The user defines the performance metric and a scoring function via drop-down lists. Scores for each region are then combined with a separate scoring function (Figure 4) to derive an overall score for use in optimizing.

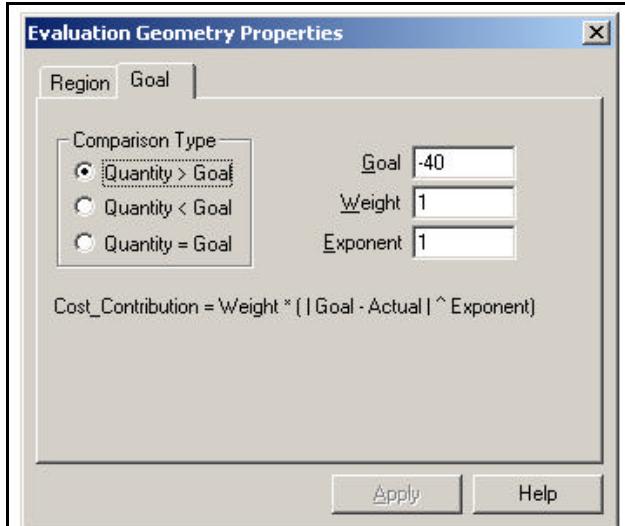


Figure 4 Evaluation region property page indicating how the desired level of jamming for each region is specified and how the relative weighting between regions can be controlled.

One of several multi-dimensional optimization algorithms can be selected to find the next trial of jammer locations and configurations to maximize (minimize) the overall score. GIJET™ will also include features to speed up the optimization process including:

1. Dynamic control of the search space (e.g., limiting the jammer locations to a coarse grid during initial phase of search).
2. Dynamic control of function evaluation (e.g., ignoring terrain, propagation effects, and detailed modeling of adaptive receivers during initial phase of search).
3. Search initialization based on practical experience and heuristic rules. This can be quite powerful if good initial guesses can be found. Route planning is one area where good initial guesses may be available.

This flexibility in controlling optimization is achieved using a scripting mechanism that the user defines via a built-in editor. A limited scripting capability was included in the GIJET™ prototype (Figure 5). This allows the user to select

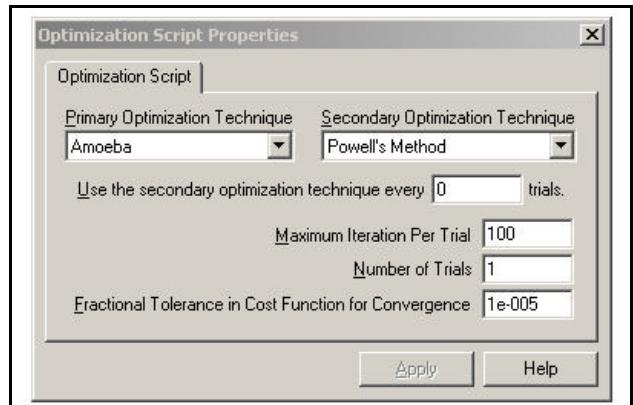


Figure 5 Simple optimization script of GIJET™ prototype code. The prototype allows the application of up to two techniques (out of four choices) in a user-defined sequence.

from among four possible multi-dimensional optimization algorithms and to insert a secondary search method after a set number of trials with the primary method. The four optimization algorithms included are: a variation of the downhill simplex method called "Amoeba", a version of Powell's direction-set method, a genetic algorithm, and a simulated annealing algorithm [1,2].

Once a minimum-cost solution is found, it is usually most interesting to view a map of GPS performance over the evaluation regions. This is termed an analysis in GIJET™. Analyses are specified via the GUI in a manner similar to the specification of evaluation regions. Figure 6 shows an example analysis result computed with the GIJET™ prototype for the optimum solution to our example problem.

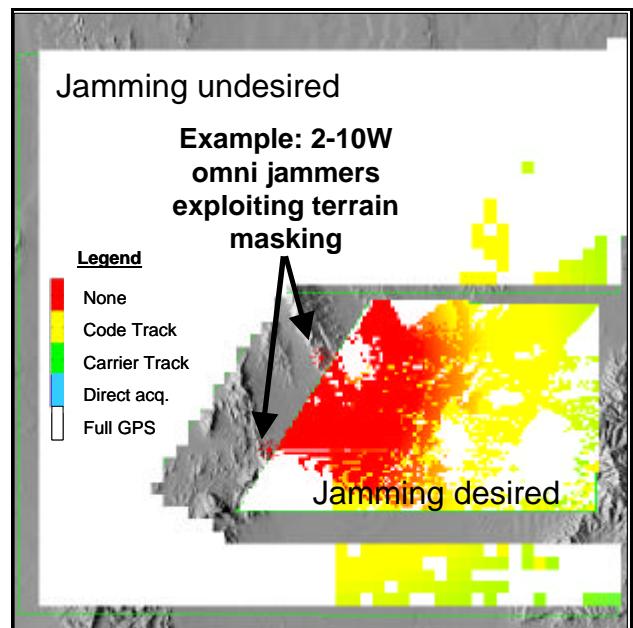


Figure 6 Map of jammer performance for the solution to the example problem. The color indicates the state of the GPS receiver at each point within the evaluation region.

The colors in the map indicate the GPS state for a receiver at each point. Editing tools are provided to customize the display.

By generalizing the notion of an evaluation region to an arbitrary set of points in *space and time*, GIJET™ can be used to solve other GPS-related optimization problems. For example, if the set of evaluation points defines an aircraft trajectory, then route planning can be achieved by optimally choosing the way-points subject to constraints (i.e., kinematic limitations, fuel capacity and usage, mission objectives, etc.).

Much of the on-going GIJET™ development is directed toward development of additional tools, algorithms, scripting capabilities, and file import/export capabilities specifically to support route planning in GPS-denied areas.

KEY COMPONENT MODELS

Environmental Models

The earth model in GIJET™ is a three-dimensional representation of the earth's surface derived from the Digital Terrain Elevation Data (DTED) database, a product distributed by the National Imagery and Mapping Agency (NIMA). The user selects the region of interest by pointing-and-clicking on the globe, after which the code prompts the user to browse the required CD volume for the appropriate terrain height data. Land cover and cultural features such as roads may be entered in similar fashion.

Three propagation models are included in the GIJET™ prototype: a simple free-space spherical propagation model, the Spherical-Earth Knife-Edge diffraction model (SEKE [3]) and the Navy's Advanced Propagation Model [4]. The former is adequate for most instances where either a jammer or a receiver is at high altitude or when a "quick look" is all that is desired. SEKE is a higher-fidelity model that is appropriate when multipath or propagation over the horizon, via either refraction or diffraction, must be taken into account.

The Navy's Advanced Propagation Model (APM) is a higher-fidelity model for specialized propagation over water or in littoral areas. APM includes more complex phenomenon such as ducting. Meteorological data will be imported to support APM modeling, if desired.

Two additional models will also be added to GIJET™ in the future – the Terrain Integrated Rough Earth Model (TIREM) and the Spherical Earth Model (SEM). These two models are being added to GIJET in order to allow GIANT™ users to maintain consistency across GPS applications. This will also ensure consistency between GIJET™ and GIANT™.

Signal Models

At each point in the evaluation region, the GPS signal (S_i) for each satellite vehicle (SV), the interference signal (J_k) for each jammer, and the noise level are computed according to:

$$S = \frac{P_T G_T G_{Ri} I^2}{(4p)^2 R_T^2 L_R L_{Prop}}$$

$$J = \frac{P_J G_J I^2 G_{Rj} B_D}{B_J f_w (4pR_J)^2 L_R}$$

$$N = kTB_D F$$

and where the parameters are defined in Table 1. The ratio of each SV signal to the total interference is then compared against a user-defined set of thresholds which are used to characterize the receiver's ability to acquire or maintain GPS signal lock:

$$\frac{S_i}{I} = \frac{S_i}{\sum_k J_k + N} < T_{RxState}$$

The ratio of the total-signal-plus-interference to noise is also tested against the receiver's dynamic range specification (DR_{Rx} , a user input) to determine whether the receiver electronics are saturated:

$$\frac{\sum_i S_i + \sum_k J_k}{N} > DR_{Rx}$$

Receiver dynamic range is an important consideration when (1) the receiver is a low-cost commercial unit which is not designed for a high-interference environment, or (2) a military receiver is operating in the vicinity of a high-power pseudolite that transmits an auxiliary GPS signal for the purpose of overcoming jamming.

Note that this formulation assumes that GPS signals as well as interference sources are sufficiently uncorrelated with each other that the power of the sum is equal to the sum of the individual signal powers. This is a good assumption for the GPS signals in the absence of multipath or specific types of coherent jamming. Multipath effects (gain or loss) are included in specific propagation models. Particular coherent jammer effects (gain or loss) are handled via the user-defined jammer waveform "factor". This is the same mechanism used in GIANT™.

Table 1

S	Receive signal power from SV	J	Receive jammer power from jammer
P_T	Transmit power from SV (includes losses)	P_J	Transmit power of jammer
G_T	Transmit antenna gain	G_J	Transmit antenna gain of jammer
G_{RS}	Receive antenna gain toward SV	G_{RJ}	Receive antenna gain toward jammer
?	RF wavelength	B_D	Receive detection bandwidth
R_T	Distance from receiver to SV	B_J	Jammer signal bandwidth
L_R	Receive loss	f_w	Jammer waveform factor (compression gain)
L_p	Signal propagation loss	F	Receive noise figure

When considering advanced receivers with space-time adaptive processing to reject interference, estimating system performance can become much more complex and computationally intensive. Toyon's approach is to compute estimates of the space-time covariance matrix for any adaptive receivers and use this information to derive estimates of the gain (or loss) that should be applied to each SV signal and jammer signal. With these corrections, GPS tracking states measurement accuracy will be computed as before based on the equations given in Kaplan [5].

SUMMARY

Toyon Research Corporation is developing a software toolbox for the Navy to evaluate mission performance and perform route planning in a GPS-denied areas, as well as to optimize jammer placement and configuration for self-protection missions or planning anti-jam equipment tests. Rather than relying on a single optimization algorithm, the toolbox includes multiple optimization algorithms, a flexible means of controlling their application, and a scripting capability for easy customization to particular classes of problems. A prototype version of the toolbox has been delivered to the Navy in Phase I of the development program.

The GIJET™ prototype succeeded in demonstrating all the key elements of Toyon's "toolbox" approach to the jammer placement problem. The Phase II effort will develop the prototype code into a tool capable of solving optimization problems over a wider set of spatial/temporal geometries.

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